THE NATURE CONSERVANCY'S
MAPPING OCEAN WEALTH PROJECT:

FISHERIES ECOLOGY, ECONOMICS AND ALTERNATIVE LIVELIHOODS IN THE GULF OF CALIFORNIA, MEXICO.

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Humans and fisheries

Marine resources have been extracted for human consumption for centuries (Jackson et al. 2001). Recent advances in technologies since the 1950's, now mean that we are able to fish harder for longer, and with more accuracy (Eigaard et al. 2014). The increase in human populations globally has also lead to an increased pressure on fish stocks for aquaculture (Naylor et al. 2000) and livestock feeds (Fré0n et al. 2013). Together, the ability to extract marine fishes and our increased requirements for protein (Tacon and Metian 2013) has had significant effects on global stocks (Myers and Worm 2003, Pauly et al. 2002) (Fig. 1A). Many commercial fisheries have shown declines in catch whilst fishing effort has increased over the last 65 years (Watson et al. 2012) (Fig. 1B). At present 52% of all commercial stocks are fully or overexploited (17%) (FAO 2016).

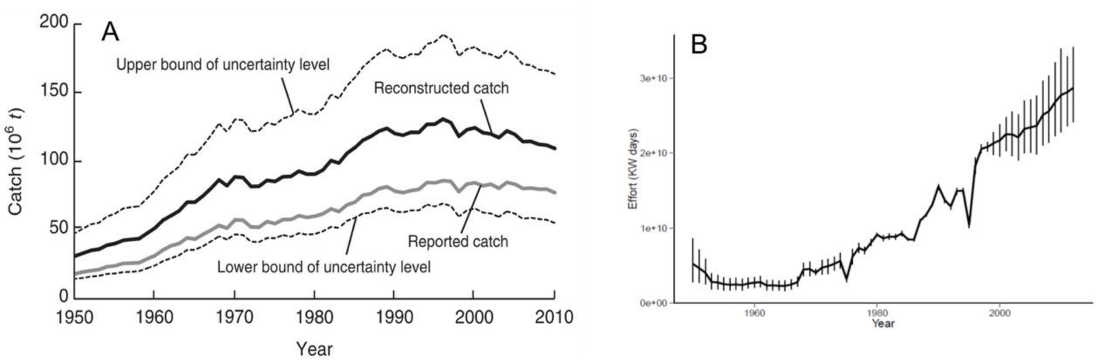


Figure 1. Graphs showing the global marine fisheries catches and reconstructed catches that account for unreported fish landings using data from the Food and Agriculture Organization (A) and the increase in global fishing effort measured as KW days (vessel power output) (B). Taken from Pauly and Zeller (2016) and Bell et al. (2015) respectively.

Our oceans provide a wealth of food resources but it has become apparent that current practices need strict regulation, and in many cases reduction, if we are to continue extracting fish at levels close to those of recent years (Worm et al. 2009). Continued reductions of fish populations and stock collapses will have both significant ecological and economic consequences for human populations (McClanahan et al. 2013). This is particularly so, although not limited to, those villages, towns and cities that rely directly on fishing for food and / or employment (Teh and Sumaila, 2011).

Ocean Wealth

Considering the impacts that we have on our oceans through fishing, and the economic gains that fishing activities yield from them, it is not surprising that we often measure ocean wealth in terms of fish biomass (Ye et al. 2012). This view is, however, somewhat narrow considering the multiple ecosystem services the ocean provides us additional to fishing such as coastal protection, recreational activities, oxygen production and carbon sequestration (Costanza, 1999). More recently, conserving fish biomass is increasingly linked to non-extractive benefits often related to ecotourism ventures that are now proving promising alternatives to fishing in certain circumstances (Ditton et al. 2002, Lemelin et al. 2012, Zwirn et al. 2005). The benefits of rebuilding global fisheries overall significantly outweigh the costs (Sumaila et al. 2012), which has reiterated the idea in the ecological sciences that ocean wealth is primarily attained through fisheries management.

If, however, we are to consider the future use of marine ecosystems with more holistic, sustainable visions it will be necessary to shift to a new paradigm. This must consider more than just target fisheries revenues when evaluating ocean wealth. Such a shift has already become evident within fisheries science through the now commonly recommended approach of, Ecosystem Based Fisheries Management (EBFM) (Pitcher et al. 2009), which aims to move away from managing single target species towards managing whole ocean ecosystems. This therefore accounts for (i) the degradation of ecosystems overall and (ii) for the ecological requirements of non-target species and habitats (Pikitch et al. 2004).

In addition to the vast quantities of fish biomass that our oceans provide, to truly evaluate wealth we must consider the other ecosystem services we gain from marine ecosystems (Farber et al. 2002, Bamford et al. 2002). For our oceans and coasts, other services include coastal protection from rising sea levels and storms, carbon sequestration that helps mediate climate change and cultural values associated with our professional and recreational use of marine systems (Liquete et al. 2013). If we take a holistic approach that accounts for more than just fish biomass we will have a better understanding of the true wealth within our oceans. We will also approach future management in a way that will likely result in management decisions that indirectly benefit more than singularly defined ecosystem services. This will provide more benefit for human populations relying on marine systems and thus lead to a future with more successful and sustainable ocean management.

The Gulf of California

The Gulf of California (the Sea of Cortez) between Mexico's mainland and the Baja California Peninsula is an excellent place to demonstrate the potential of changing paradigms from the extraction of fish biomass to balances between fisheries and conservation. It is an area of outstanding marine diversity and productivity, the major economy of which has come from the exploitation of this productivity in the form of fisheries (Fig. 2). Marine fisheries in the region account for 70% of Mexico's fisheries catches (756 thousand tonnes in 2013 = $223 million USD) (Cisneros-Mata 2010). Similar to global fish stocks, the majority (60%) of Mexican fish stocks are fished at or above sustainable levels. This threatens both the ecological and economic stability of Mexico's marine ecosystems, including the Gulf of California (Cisneros-Mata 2010).

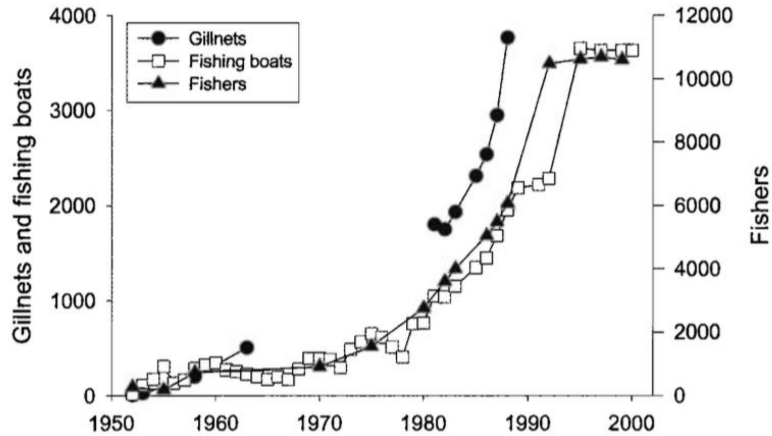


Figure 2. Changes in the numbers of gillnets and fishing boats (left hand side) and fishers (right hand side) in the Southern Gulf of California. Taken from Sala et al. 2004.

The following pages describe the value of the Gulf of California based on its fisheries resources. It highlights the struggles the heavily exploited ecosystems face and the importance of a new ecosystem-based approach that accounts for habitats used by many fish populations from juveniles to adults. A paradigm shift from fish extraction to alternative means of revenue from the Gulf is described and potential future sustainable revenues calculated. Finding a balance between current fisheries and more sustainable futures is essential if over-exploitation of the Gulfs fish stocks is to stop whilst revenues that support local human populations continue.

Fisheries Economics

Fisheries generate a wide range of economic benefits to society. Fishery catch and revenue contribute directly to local and global food security (Golden et al. 2016) and support millions of fishers, including women and children (Teh et al. 2011), worldwide. These direct benefits provide inputs to wide value chains that ripple throughout the economy and connect with broader international markets (Dyck and Sumaila 2010). However, fisheries overcapacity and growing coastal populations can lead to a dissipation of potential resource profits (Clark 2004), creating situations where, aside from general overfishing, total fishery revenue is divided over many fishers and thus contributes very little income to each household.

It is important to consider both the total revenue made from a fishery as well as the employment generated by that fishery. Understanding current fisheries-related revenues and employments means it is possible to evaluate whether further investment in current fisheries is viable based on the potential revenue gains divided by the number of new incomers to the industry. Considering fisheries are an exhaustible resource, it is also important to consider that if more and more people work in the fisheries sector, there will be a point at which the amount of fisheries resources being extracted is maximized. Beyond this point the amount of revenue earned by each person is reduced, as the extracted resources have to be shared amongst more workers.

Using data from the Mexican Nation Institute of Statistics, Geography and Informatics (INEGI), we compiled a database at the municipality level that confirms that in 1998 fisheries in the Gulf of California netted a total of $ 115 million USD (values for Municipalities in Baja California and Baja California Sur include fisheries from both, The Gulf of California and the Pacific). This value dropped to $ 90 million USD by 2008. The average salaries of fishers over the same period declined from $ 1,982 USD to $ 1,583 USD. Unfortunately, we still do not have the data from the last decade (2008-2018), but current projects and studies suggest that the declining economic trend is still happening (pers. comms. Aburto) (Fig. 3).

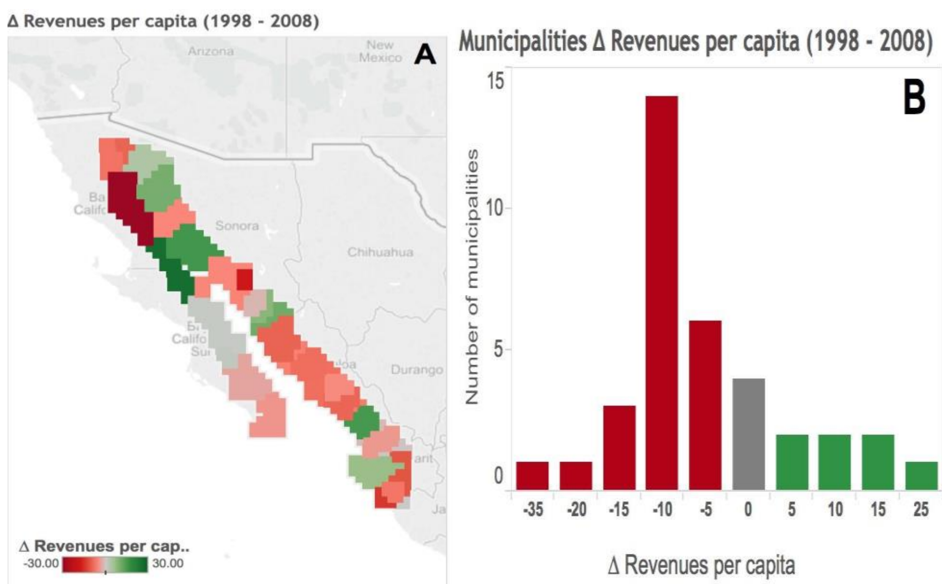


Figure 3. Map showing the changes in the revenues per capita between 1998 and 2008 for each municipality in the Gulf of California (A). Bar plot showing the number of municipalities and the amount of change in revenues per capita for each (B). Green represents increases, reds indicate decreases and grey represents no change.

Reasons for this decline are not related to: (i) reductions in fish catches and/or (ii) an increase in the total number of fishers and workers associated with the fishing industry working in the Gulf (57 versus 56 thousand in their respective years). Overall these 2 parameters have remained approximately consistent since the 1990’s. These economic declines instead are likely to be related to reduced values of catches in local and international markets, mainly by the phenomenon known as "fishing down the food webs" (Sala et al. 2004, Erisman et al. 2010), where today landings are represented mostly by lower trophic species with less economic value, compared with the high trophic level species like sharks and big groupers that used to represent the majority of landings some decades ago and had high prices in the markets.

Fisheries Ecology

Natural ecosystems are complex. One animal can interact both with individuals of the same species as well as many un-related individuals with which it shares its habitat. Interactions between individuals may be related to trophic links (who eats who), or competition for resources such as food or space. If we are to move towards the sustainable harvest of commercial fish species it is essential that we understand more than just how much we take from the ocean. We must also recognize that the extraction of one individual has consequences for others left in the system. This Ecosystem Based Approach to Fisheries Management (EBFM) (Pitcher et al. 2009) must also understand how individuals grow and how large their populations can potentially become. This provides information on the potential of non-fished systems, or how many fish we could potentially have if we stopped fishing in an area – but this will be dependent on the habitat and other species mentioned above.

In fisheries management and conservation there are 4 important parameters that we must understand that relate to a species growth, potential population size, the level at which we can sustainably extract from the population and the position the species occupies in the food chain. These parameters are described in more detail below:

Intrinsic rate of growth (r)

This is a measure of how much a population can grow in number, in a given amount of time (i.e. the number of new individuals per month, season or year).

Carrying capacity (K)

This represents the maximum number or biomass of individuals that a particular area, habitat or ecosystem can hold.

Habitat use

This provides information on what types of environments a species lives in and how much space within a particular habitat a species inhabits. Habitat types in the Gulf of California include mangroves, rocky reefs, sargassum seaweed beds to name a few.

Maximum Sustainable Yield (MSY)

Renewable resources such as fish can be harvested at various levels such that the biomass extracted is equal to the surplus production of a stock. The highest rate of sustainable production is that maximum sustainable yield, the most catch that can be taken without the population decreasing over time.

Trophic level

This is a quantitative reflection of the level an organism occupies in the food web, where primary producers have a value of 1. Predatory species like barracuda and jacks that prey on many fish species are high up in the food chain and therefore have a higher trophic level than species that feed on invertebrates like mullets and chubs. The trophic level can also be used as a proxy measure of the size of a species or vice versa, the higher the trophic level, generally, the larger the species in its adult stage.

The graphs below (Figure 4) demonstrate how each of these measures can be used to provide information on fish species in an area, in this case the Gulf of California.

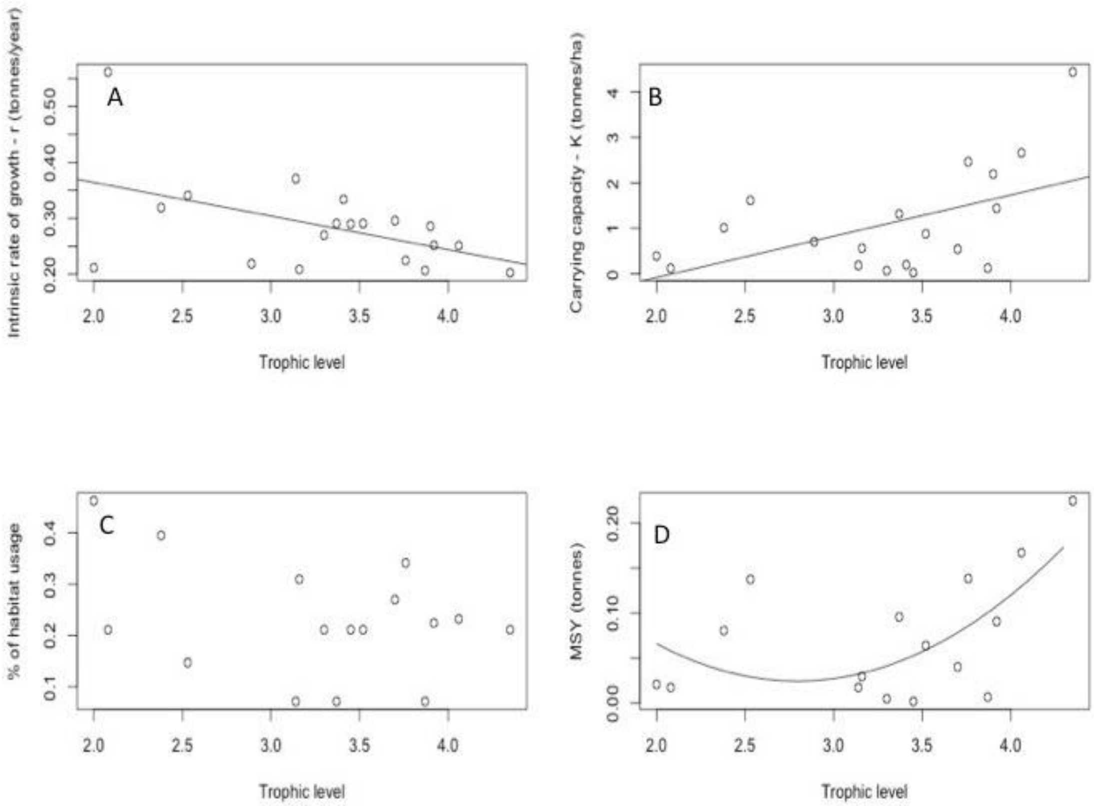


Figure 4. Relationships between trophic level and (A) intrinsic rate of growth (r), (B) carrying capacity (K), (C) % of habitat used, and (D) MSY for fishes in the Gulf of California. Lines in the plots show statistically significant relationships.

The graph above demonstrates how larger fish species grow more slowly (lower r = less fish per year) than smaller species (those at lower trophic levels) (Fig. 4a). Even though the growth of the larger fish species is slower, they can also reach higher maximum levels of biomass (K) than the small fish species (Fig. 4b). For fishes in the Gulf of California there is no relationship between the amount of habitat use and the trophic level of the species (Fig. 4c). However, of the species analyses herein, the larger the fish, the larger the annual sustainable yield (Fig. 4d). Although not to the same extent as these large fish, the very small fish also produce high sustainable yields due to their fast growth rates (r). The 18 species used in the graphs above can be seen in Table 1 below, along with the parameters for each species.

Table 1. Biological parameters of the 18 fish species used in the analyses above.

Group	r	K	% of habitat use	MSY (tonnes per hectare)	Trophic level
Parrot fishes	0.212	0.3905	0.462	0.021	2
Mullet	0.561	0.1229	0.211	0.017	2.08
Surgeon fishes	0.319	1.01	0.395	0.081	2.38
Chubs	0.341	1.613	0.147	0.138	2.53
Sergeant Majors	0.219	0.7045	0.04	0.039	2.89
Puffer fishes	0.371	0.1855	0.071	0.017	3.14
Trigger fishes	0.209	0.5623	0.31	0.029	3.16
Breams	0.27	0.0702	0.211	0.005	3.3
Grunts	0.291	1.316	0.071	0.096	3.37
Soldier fishes	0.334	0.1984	0.211	0.017	3.41
Scorpion fishes	0.29	0.0238	0.211	0.002	3.45
Rays	0.291	0.8775	0.211	0.064	3.52
Goat fishes	0.296	0.5423	0.27	0.04	3.7
Cardinal fishes	0.225	2.462	0.341	0.138	3.76
Groupers	0.286	2.192	0.296	0.157	3.9
Snappers	0.252	1.44	0.224	0.091	3.92
Jacks	0.251	2.658	0.024	0.167	4.06
Barracuda	0.203	4.431	0.211	0.225	4.35

<u>Fisheries catches compared to sustainable yields</u>

By comparing the current catch of fishes to their predicted Maximum Sustainable Yields it is possible to evaluate the approximate sustainability of a fishery. For example, if a fishery is taking 10 tonnes of mackerel per year, yet the MSY for mackerel in the fishery area is 8 tonnes per year, it demonstrates that the fishery is taking 2 tonnes too much per year. This fishery would therefore be noted as unsustainable as over the long-term fishing at such a level would mean a reduction in the number of fish in the population. To understand what such results mean economically the biomass of fish can be converted into a monetary value based on the market price of the fish when it was caught. In this way it is also possible to convert theoretical MSY levels for a species into economic revenues if the species was fish sustainably.

In the Gulf of California catches are highest for medium to large size fish (trophic levels 3.5-4) (Fig. 5a). The theoretical MSY is highest for the larger fish, although the smallest fish are also able to produce a relatively high MSY based on their high intrinsic growths (Fig. 5b). It is worrying that the current catches of fishes in the Gulf of California range from close to 0 tonnes per year to 5,000 tonnes per year, whilst the theoretical MSYs range from zero to 50,000 tonnes per year. MSYs that are ten times higher than current catch levels indicates that the Gulf of California could provide fishers with much more fish than they are currently extracting.

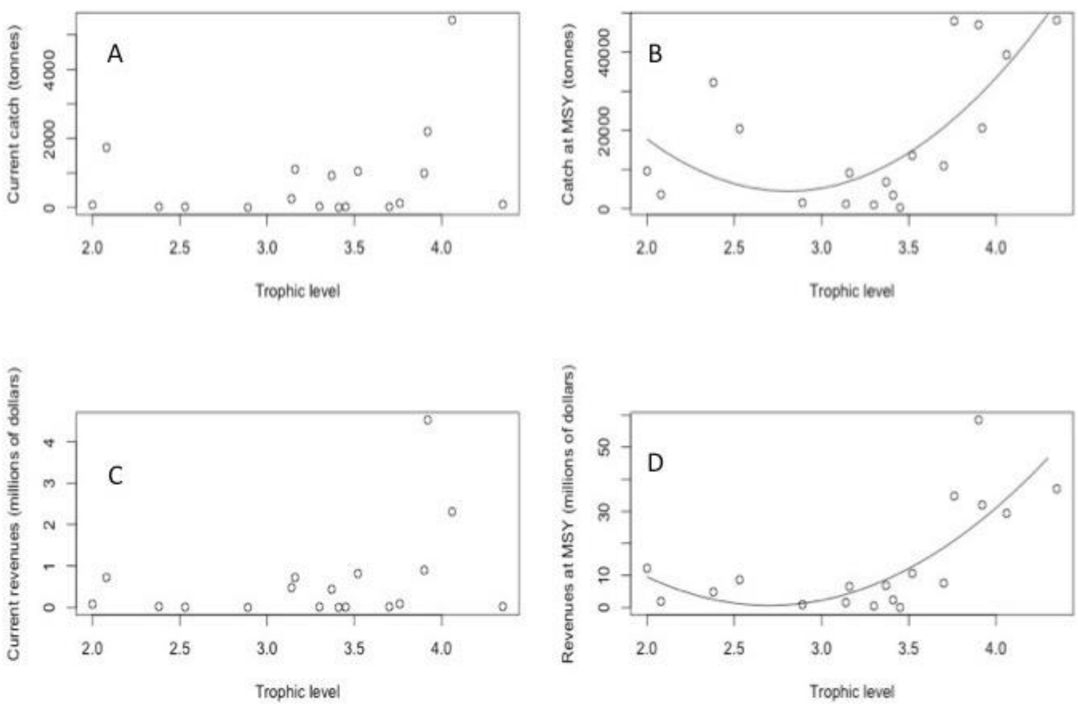


Figure 5. Relationship between trophic level and (A) current catch, (B) catch expected at MSY, (C) current revenues, and (D) revenues expected at MSY. Lines in the plots show statistically significant relationships.

Economic revenues from fisheries catches

Converting the catches and theoretical MSYs of the fishes to market values (US dollars) shows the same relationships as those of the catches. The highest fisheries revenues in the Gulf of California come from medium to large sized fish (trophic levels 3.5-4) (Fig.

5c). If the fishes of the Gulf were caught at MSY the revenues would be highest for the highest trophic levels (Fig. 5d). Similar to the MSY biomasses of these fish, the smallest fish species contribute significantly to the potential revenues if exploitation does not exceed MSY levels. The revenues of fishing at MSY levels is ten times greater than the current revenues that are being made from fisheries in the Gulf of California.

Single-species MSY, while the overarching goal of most Mexican fisheries, are difficult to achieve in multi-species settings (Walters et al. 2005). We therefore calculated the theoretical catch of each species if each spatial area were fished to achieve the total maximum sustainable yield summed over all species (e.g. Cheung and Sumaila 2008). i.e., instead of a fishing vessel fishing each species at MSY, it would fish the whole area at MSY, where some individual species would be slightly overexploited and others slightly underexploited. The spatial patterns observed from the single-species MSY model would not change substantially, yet the overall catch is decreased by an average of 5% (0-31%) in each cell. This highlights the importance of recognizing the dynamics of real-world fisheries in the Gulf of California (and around the world), that must necessarily shape the range of models, policies, and implementation strategies to achieve social, economic, and ecological sustainability.

The difference between the current catch and the theoretical MSY is likely due to a long history of overexploitation of fishes in the Gulf which now means that many fish populations are being fished unsustainably and are declining year by year (Erisman et al. 2010). There is also evidence of this overexploitation in the maximum individual length of fish species, which has decreased approximately 45cm in only 20 years (Sala et al. 2004). The graphics above (fig. 5A-D) demonstrate that it is both ecologically and economically advantageous to fish at levels that do not exceed the Maximum Sustainable Yield of each fish species. More fish would be present in the Gulf and more money would be earned from the fisheries if each species is fished at MSY levels. The 18 species used in the graphs above can be seen in Table 2 below, along with the parameters for each species comparing current practices to potential sustainable practices (MSY).

Table 2. Comparison between expected value of catch and revenues at MSY and current landings.

Group	Trophic level	Catch at MSY (tonnes)	Difference between multispecifc and single species MSY	Current catch (tonnes)	Difference in catch (tonnes)	Revenu MSY (M USD
Parrot fishes	2	9698	-5%	73.6	9624	12.2
Mullet	2.08	3688	-11%	1739.5	1949	1.93
Surgeon fishes	2.38	32232	-1%	21	32210	4.84
Chubs	2.53	20460	-3%	18.6	20441	8.62
Sergeant Majors	2.89	1552	-7%	0.2	1552	0.86
Puffer fishes	3.14	1245	-3%	258.2	987	1.58
Trigger fishes	3.16	9217	-2%	1108.5	8108	6.56
Breams	3.3	1014	-2%	30.5	983	0.48
Grunts	3.37	6928	0%	926.1	6002	6.88
Soldier fishes	3.41	3545	-31%	0.2	3544	2.36
Scorpion fishes	3.45	369	-1%	20.7	348	0.03
Rays	3.52	13659	-2%	1053.7	12605	10.6
Goat fishes	3.7	10974	-7%	16.4	10958	7.62
Cardinal fishes	3.76	47893	-3%	124.6	47768	34.7
Groupers	3.9	46957	-4%	995.7	45962	58.5
Snappers	3.92	20615	-2%	2203.7	18412	31.9
Jacks	4.06	39287	0%	5425.4	33862	29.3
Barracuda	4.35	48115	-5%	87.5	48027	37.0
Total		**317,448**	**-5%**	**14,104**	**303,342**	**256**

At present the current annual revenue of the 18 fisheries analyzed above is 11.16 million dollars USD for the whole Gulf. This value could be twenty times higher (256.32 million USD for the whole Gulf) if the same fish species were fished at MSY levels. Current fisheries revenues in the Gulf of California are highest off the coast of the middle of Sinaloa (0.04 million USD) and Nayarit (0.15 million USD), and lowest in the upper Gulf and around the Midriff Islands each of which shows revenues of just 300 thousand USD per 500 km^2 (Fig. 6a). The theoretical revenues that could be made if fisheries were fished at MSY levels are highest around the Midriff Islands (1.37 million USD), La Paz (1.2 million USD) and Nayarit (1.49 million USD) per 500 km^2 (Fig. 6b).

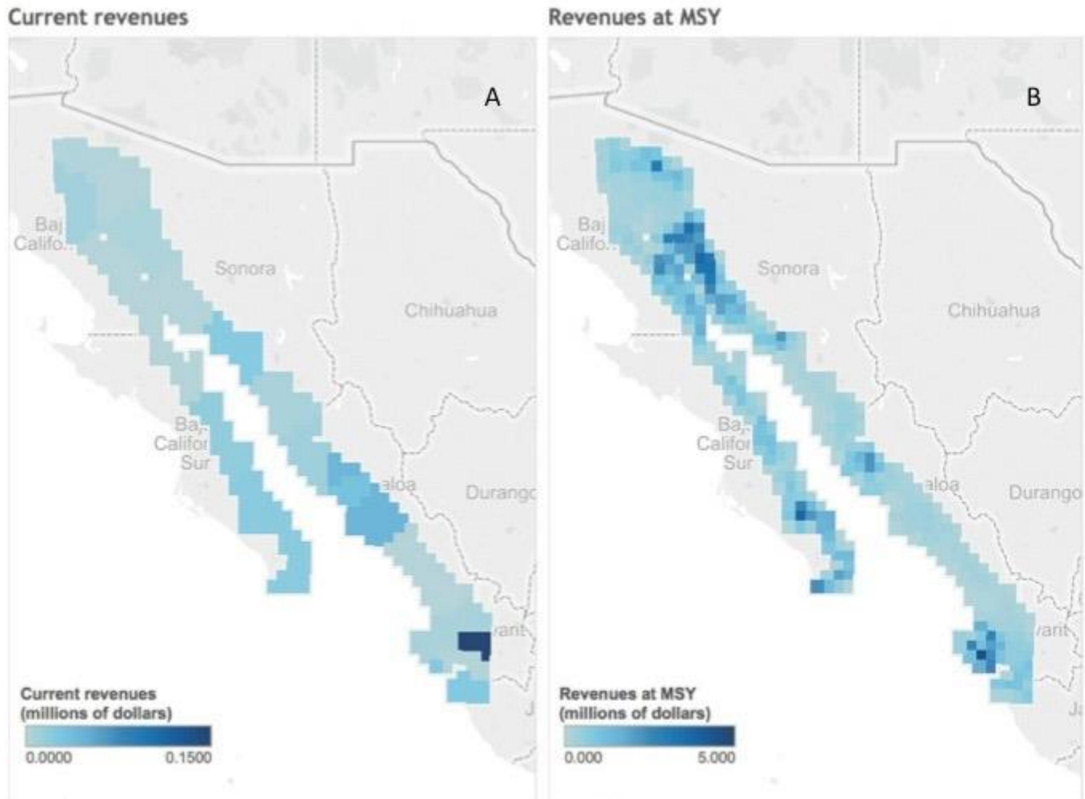


Figure 6. Maps of the revenues generated by the fisheries at the (a) current levels of extraction in millions of dollars and (b) MSYs.

Habitat distributions and fisheries productivity

Many marine fish species rely on specific habitats for the recruitment and growth of their juvenile life stages (Aburto et al. 2007, 2009). The habitats are often structurally complex providing protection from predation and conspecific competition (Almany 2004). In the Gulf of California, the roots of mangrove forests and the complex sargassum brown algae provide two important habitats for a number of species (Mumby et al. 2004, Wells & Rooker, 2004). The commercially important snappers (*Lutjanus sp.*) and groupers (*Mycteroperca sp.*) are two such groups of fish species that rely on sargassum and mangrove habitats respectively for juvenile recruitment and growth (Aburto-Oropeza et al. 2010).

The distribution of these mangrove and sargassum habitats in the Gulf of California (GoC) follows a clear latitudinal pattern (Fig. 7). The majority of mangroves in the Gulf are located along the mainland coast towards the south, in some cases are 100 times more abundant than on the peninsula coast (Fig. 7a). Mangroves are mainly associated with warm water, which shifts their distribution to the south. Most of the sargassum habitats occur along the peninsula coast and around the Midriff islands in the north where water is colder, thus shifting their distribute on to the north (Fig. 7b).

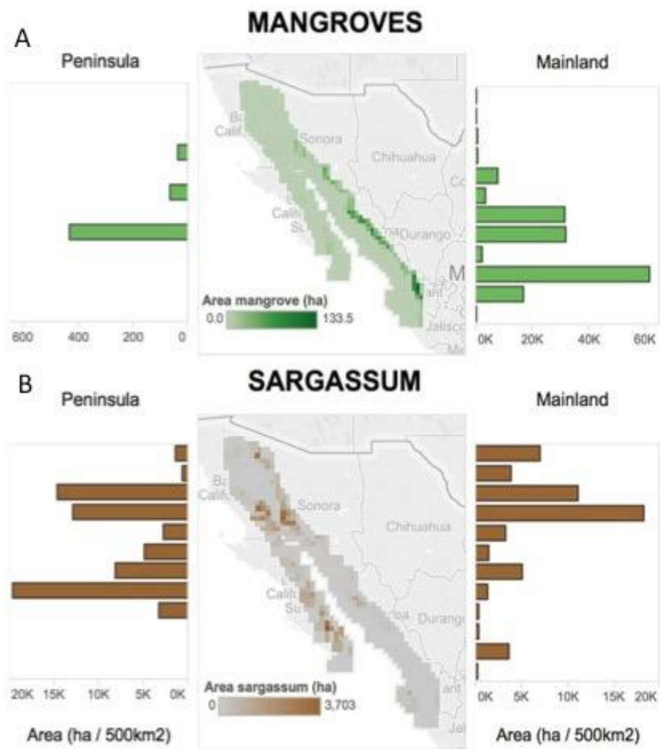


Figure 7. Maps showing the distribution of mangroves (A) and sargassum (B) in the Gulf of California. The bars represent the amount of each habitat type on the peninsula (left hand side) and the mainland (right hand side) of Mexico. The length of the bar corresponds to the amount of habitat at that latitude and the position of each bar corresponds to the specific latitude. Each bar represents one degree of latitude and is scaled to the corresponding habitat map.

<u>Snapper and Grouper nursery habitats and production</u>

Considering mangroves and sargassum habitats confer numerous advantages to juvenile snappers and groupers respectively, it is not surprising that more of each of these habitats means more adult snappers and groupers. Rocky reef habitats with sargassum present produce 34% more groupers than habitats with no sargassum (Fig. 8a).

Similarly, 54% more adult snappers develop as juveniles in mangrove habitat areas than in areas only with rocky reefs (Fig. 8b).

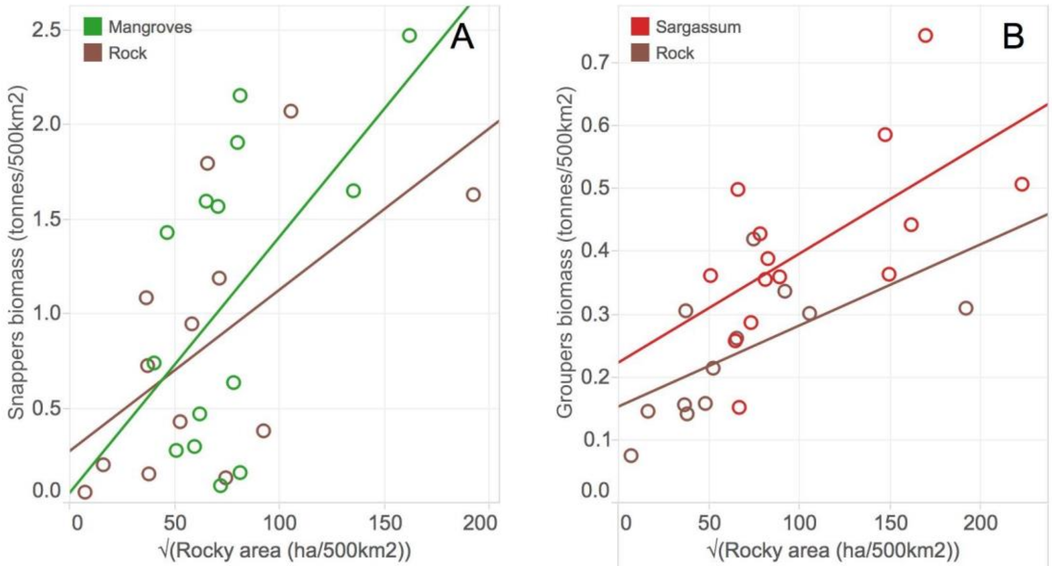


Figure 8. Scatterplots demonstrating the relationship between rocky reef area and the underwater biomass of snappers (A) and groupers (B). The brown dots in each plot represent areas that only contained rocky habitats, and the red and green represent the areas with rocky habitat plus mangrove and sargassum habitats respectively. Lines in the plots show statistically significant relationships.

The occurrence of favorable habitat confers distinct advantages for any species, in the above case mangrove forests and sargassum beds for the juveniles of snappers and groupers respectively. If fisheries in the Gulf of California worked at sustainable levels (MSY or below) mangrove areas could produce 61 tonnes per hectare of snappers and sargassum beds 185 tonnes per hectare of groupers (Fig. 9a and 9b). The advantage offered by the mangrove and sargassum habitats is evident when the catch at MSY is compared to areas without the respective habitats. Without mangrove and sargassum habitats rocky reefs would produce 18.2 tonnes per hectare less of snapper and 86.5 tonnes per hectare less of grouper. The same relationships are echoed in terms of the increased revenues that are produced in areas with mangrove or sargassum habitats (Fig. 9c and 9d).

The importance of habitat cannot be underestimated when considering the future of marine fish stocks and evaluating current fishery practices. It is essential that fisheries management consider both the amount of fishing taking place and where that fishing occurs. Reducing fishing effort in areas with habitat important for commercial species growth and recruitment will likely produce significantly more fish biomass over the long-term than reducing fishing in areas less important for the species of interest. For this reason Maximum Sustainable Yield targets must also be incorporated with habitat knowledge of targeted fish species, particularly in cases where spatial management such as Marine Protected Areas or No Take Zones are being considered to replenish or conserve populations.

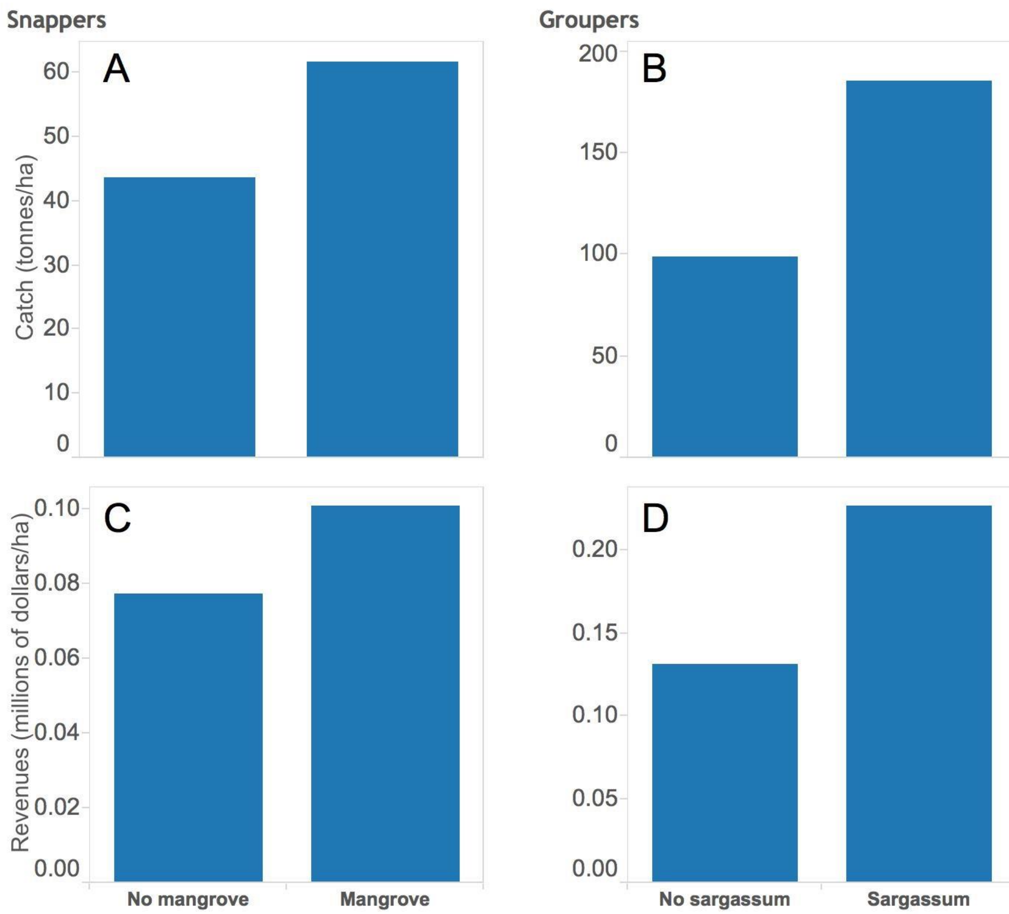


Figure 9. Bar graphs comparing the annual predicted average at Maximum sustainable Yield (above) and the annual revenues per if fishing occurs at MSY levels (below) for snappers (A and C) and grouper (B and D).

Humans and shared fishery resources

Human population distributions are often determined by resource availability. Many coastal populations have historically been founded on rich marine fishery resources (Castilla 1999). It is therefore not surprising that some of the worlds densest populations are located near highly productive marine areas. As human populations continue to grow, however, coastlines become fuller and less productive areas are inhabited and impacted. The Gulf of California is no exception. A historic wealth and diversity of fisheries resources have been reduced by large growth in the fishing sector (Cisneros-Mata 2010), over-exploitation of many stocks (Myers and Worm 2003, Pauly et al. 2002) and growing human populations. It is important to consider two main scenarios when considering the population of fishers, and the potential revenues that can be made if fishes are extracted at MSY levels. The first is one of exceptionally high fisher population levels in areas of relatively low marine productivity, and therefore potential earnings if fisheries were fished at MSY. This would mean that many people would need to share the revenues gained from few resources. The second scenario is one in which there are relatively few fishers but high potential gains from sustainable (MSY) fisheries. This is a beneficial scenario for fishers as it means high revenues are shared between few people. At present in the Gulf there is a diverse mix of these two scenarios (Fig. 10).

Although marine conservation intuitively calls for a reduction in marine fisheries at least to MSY levels, it is important to remember that not all areas have the same natural potential. For example, an area with low mangrove density and few rocky reefs with no fishing pressure will never be able to produce high fish biomasses that can support large human population growth. It is therefore imperative that both the natural potential of the adjacent waters and habitats as well as the current fishery exploitation levels are taken into account before strict fisheries management measures are put into place.

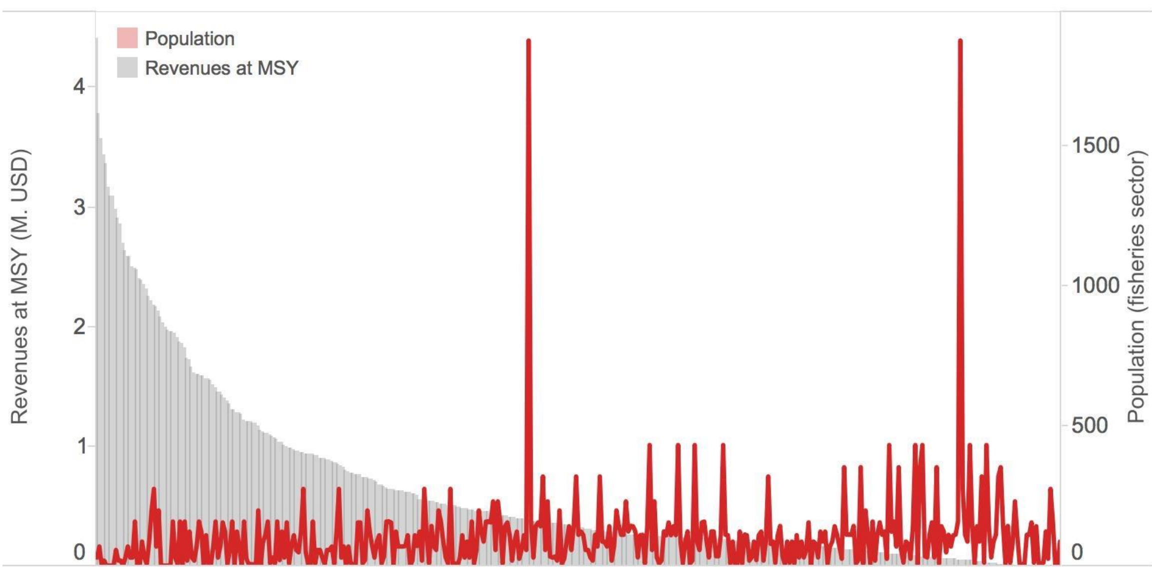
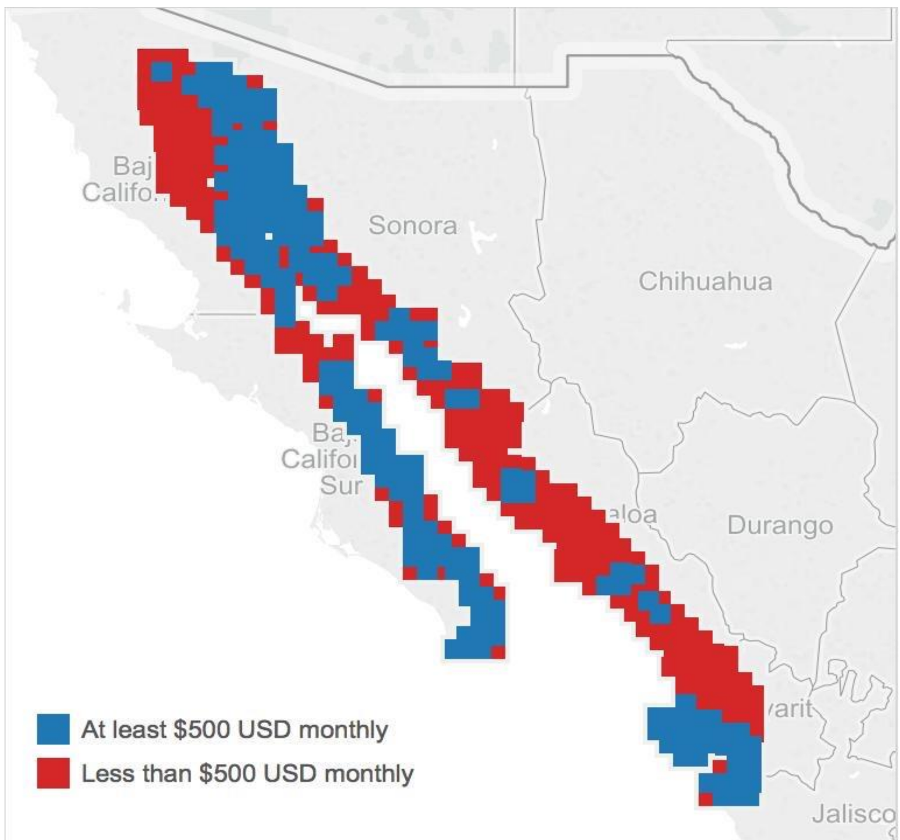


Figure 10. Revenues at MSY and human population ranked by revenues at MSY from highest to lowest.

There are both ecological and economic incentives to fishing sustainably. In general, with more fish in the sea, ecosystems are healthier and there is more potential resource that can be used by fishermen. Just because a resource is available, however, does not mean that it should be fully exploited - hence the idea of Maximum Sustainable Yield - harvesting at a level that allows the natural replenishment of fish populations so that yields can ideally be sustainable and consistent. In order to promote the idea of sustainable fishing to the fisheries sector is very important to discuss the results of changing fishing practices in terms of revenues earned. It is therefore useful to be able to demonstrate potential revenues. This idea can also be extended by dividing the total potential revenues of fishing at MSY by the number of individuals working in the fishing sector within their respective fishing grounds. The resulting map (Fig. 11) shows the potential earnings of fishers based on a threshold of $ 500 USD per month per individual



fisher from the adjacent coastline.

Figure 11. Map of potential earnings per month of fishermen based on fishing at the Maximum Sustainable Yield for all stocks. Results are divided into salaries below and above $500 USD per month (red versus blue respectively).

It is clear that there are great economic advantages to be gained if fisheries are to be fished at MSY levels throughout the Gulf. The Midriff islands, the southern half of the peninsula and the southern Nayarit coast all offer great promise in terms of earnings per fisher if a sustainable approach to fishing is taken (blue areas in Fig. 11). It is, however, noteworthy that even if fisheries resources are allowed to recover to sustainable levels through MSY fishing practices, there are areas in which the ratio of people to potential earnings is so high that salaries will still be low (red areas in Fig. 11). For these areas the only viable solution to increasing revenues in the long term is therefore to consider alternative livelihoods for some of the fishing population that lives there. If alternative approaches to revenue generation are not considered, further growths in human population levels will continue to reduce economic revenues in these areas even if sustainable fishing practices are adopted.

What's next for fisheries in the Gulf of California?

Changing paradigms from fully extractive to more conservation-minded approaches in fisheries will lead to much more favorable long-term fisheries both in terms of increased fish biomass and economic returns. However, if current practices are shifted to MSY level catches tomorrow the benefits will not be immediate. The majority of the fisheries in the Gulf have been fished unsustainably (above MSY levels) (Cisneros-Mata 2010) and many fish populations today are already severely depleted (Watson et al. 2012). In order for fish populations to bounce back to healthier levels, it is necessary to reduce the amount that fishers fish. This could be accomplished through reductions in current fisheries effort or alternatively by reducing the number of fishers working in the Gulf. Such measures will, however, mean that overall there will be less fisheries revenue earned from the Gulf's fisheries resources. Alternative livelihoods will therefore need to be sort in order to maintain income for fishers that either reduce their effort or stop fishing altogether. Marine ecotourism is one such example of an alternative livelihood that may well pave the way to sustainable marine fisheries, maintained or even increased revenues for fishers and sustainable growth in the Gulf.

An alternative to fishing - Nature-based marine tourism

One promising alternative to the continued unsustainable extraction of fish from our oceans is nature-based marine tourism. This term Marine ecotourism refers to dedicated recreational activities conducted by individuals independently or as part of a tour, relying on living marine organisms (Cisneros-Montemayor et al. 2016). An excellent example of the potential of ecotourism to bring economic returns comparable or greater than fisheries is the shark watching industry. At present shark watching operations around the world generate 314 million USD annually (Cisneros-Montemayor et al. 2013), approximately half the amount generated by shark fisheries (630 million USD). Projections estimate that in 20 years the growth in the shark watching industry will more than double to 780 million USD annually (Cisneros-Montemayor et al. 2013), a value that will likely exceed future shark fishery revenues considering continued declines in shark populations globally (FAO 2016). Such operations generate sustainable economic growth from marine resources and provide alternative livelihoods to those who will likely be affected by future reductions and collapses in fish populations if unsustainable fishing practices continue.

Two well-known success stories of nature-based marine tourism marine ecotourism in Baja California Sur, Mexico are the villages of Cabo Pulmo and Laguna de St Ignacio. Locals from both of these areas have taken the initiative to focus on charismatic species and habitats to draw tourist revenues to their communities instead of relying on money based solely on the extraction of fisheries resources.

Cabo Pulmo

Situated on the eastern tip of the Baja California peninsula, Mexico, Cabo Pulmo is a high diversity conservation success that highlights that community-managed marine reserves and tourism are viable alternative solutions to unsustainable fisheries exploitation. The small village was originally founded on pearl diving and fishing; activities that sustained the locals for many years. With time, however, as the village grew and fishing pressures on local reefs and offshore fishing sites increased, the local catches moved from sharks to reef fish and then smaller catches. After much discussion among the local fishers, the village community decided to close the local area to fishing and try and earn revenues from marine-based ecotourism activities such as sports fishing and diving. The transition from an extractive to a conservation-based approach to earnings was not an easy one. The fish populations took a number of years to bounce back during which time many questions were asked as to the feasibility of the new industry. With persistence, the locals of Cabo Pulmo began earning from their local waters in sustainable ways and today the park boasts the largest recovery of fish biomass ever recorded (Aburto et al. 2011).

Today Cabo Pulmo is designated a 100% no take marine reserve that hosts 29,000 visitors and makes a total of approximately $18 million USD per year; some of the highest per-operator ecotourism revenue in Baja California Sur (Cisneros-Montemayor et al. 2016). The community continues to educate both the old and young generations on conservation and sustainability through workshop initiatives and exchanges with other Mexican communities. In order to ensure the longer-term sustainability of the park, there is a quota for the number of users that can visit the marine park as SCUBA divers. This ensures the sustainable use of the parks underwater resources but also helps to maintain the quality of diving operations offered to visiting tourists.

Many of the tour operators in Cabo Pulmo actively participate in scientific research projects with collaborating universities. This helps both the locals and scientists understand how and why their park has become such a success and also provides an important baseline from which to work off if the community faces future threats from coastal development projects and a like.

St Ignacio

In the mid 1800's the gray whale (*Eschrichtius robustus*) industry on the west coast of the Baja California Peninsula was harvesting approximately 450 individuals in high catch years (Urbán et al. 2003). Although local communities were making considerable economic gains from the industry, it was not to last. Due to their slow-growth life history, gray whale populations in Baja suffered from significant declines from whaling even up until the early 1900's. After much discussion with the both national and international conservation groups, in 1938, the Mexican government issued a moratorium on the commercial gray whaling in Baja California (Urbán et al. 2003). Today, Mexico's Baja California population of gray whales has bounced back. Every year more than 20 thousand gray whales visit the shallow bays and lagoons along the peninsula. Of particular note is the sleepy town of St Ignacio, which through the development of 11 local ecotourism operations, turns over $ 3 million USD per year thanks to the whales calving in the lagoon (Brenner et al. 2016). Thanks to the protection of the lagoon by government laws and the longer-term visions of the locals, St Ignacio benefits from the moratorium and the small-scale sustainable nature of the local shell and finish fisheries of the area. Today 11 operators employ 216 staff and run tours to see the whales in the lagoon for over 12,000 tourists, turning over 7.2 million USD per year. Similar to Cabo Pulmo, St Ignacio's long-term sustainable vision that has shifted from a paradigm based on extraction to one based around conservation is benefiting not only people now, but will continue to into the future.

Conclusions: Finding a Balance

Human populations surrounding the Gulf of California are growing every year and fisheries are becoming increasingly exploited. The extraction of a finite resource by an industry that is increasing its effort due to reduced economic revenues, enabled by ongoing capacity-enhancing subsidies will lead to further economic declines for fishers as annual revenues are reduced by increasing costs and in some cases shared among more people. The panorama gets more complicated given reductions in the size of fish populations and reduced natural abilities to replenish what has been taken by the fishing industry. It is therefore imperative that an alternative livelihood is sort for the fishers in the Gulf of California so that exploitation of the Gulf's fisheries resources can be reduced. This reduction in fishing should lead to a situation in which every fishery in the Gulf operates at or below Maximum Sustainable Yield levels so that fish populations can replenish themselves to remain productive indefinitely, and avoid the current scenario in which continuing declines spell trouble for both the fish populations and the fishermen making a living from them.

Considering the success of Cabo Pulmo, St Ignacio, the number of registered ecotourism operators on the Baja peninsula (Fig. 12a) and the many large, charismatic species that occur in the Gulf (Fig. 12b), a viable alternative to fishing is the development of marine ecotourism operations. In order to shift, however, from an extraction-based (fishing) to an extraction-and-conservation-based (fishing and marine ecotourism) paradigm, a significant change in behavior of the Gulf's fishing industry is required. Current fishers must be educated in strategies that will help them convert some of their existing activities to tourism-based operations, and collaborations between government tourism, conservation and fishing groups must be strengthened. The younger generations living around the Gulf must be taught the value of conserving nature and the longer-term benefits of conservation-based approaches rather than shorter-term, purely extractive ones.

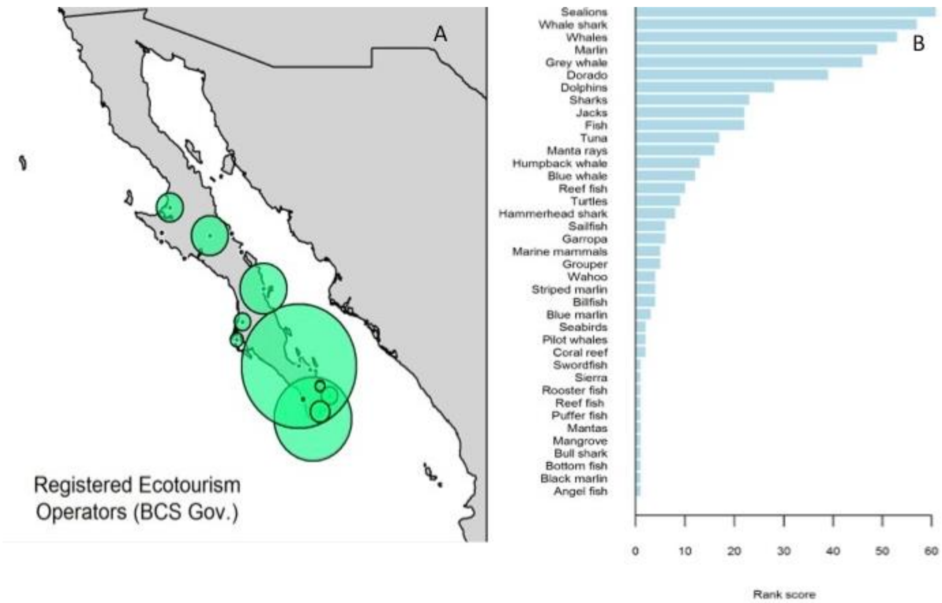


Figure 12. Formally registered marine ecotourism operators in the Gulf of California and Baja California Peninsula; bubble sizes show the number of operators scaled to the location (a) and the most important species ranked by operators of marine ecotourism operators (b). Both taken from Cisneros et al. (2016).

Areas of particular focus for ecotourism operations and priorities for sustainable fisheries working only to MSY levels are those that are home to habitats important to the species of interest. Examples include the Sinaloan coastline and the Midriff Islands area in the northern Gulf, which are home to high densities of mangrove and sargassum habitats respectively, important for snapper and grouper populations. Both of these species are of commercial interest but are also key players in reef fish populations important to dive tourism operations. Areas with high earning potential at MSY fishing levels must also be considered when focusing fishing efforts such as the Midriff islands, the southern half of the peninsula and the southern Nayarit coastline. due to the overlap of areas with ecotourism and fishing revenue potential it will be important to balance both extractive and conservation-based approaches so that revenues can be maximized by using what essentially should be complementary strategies to long-term sustainable fisheries.

Visions of the results of changing attitudes towards the Gulf’s marine resources must, however, be realistic. Reducing fishing efforts and transitioning to alternative livelihoods cannot happen overnight and fishers need to be patient whilst fish populations recover from decades of overexploitation. Nature has an amazing ability to regenerate if given time and the right conditions, but longer-term visions and goals must be set in order for success to occur. If a balance between marine fisheries and ecotourism can be found in the Gulf of California, fishers can make good livings, fish populations can be utilized sustainably, and future generations can look forward to a productive and healthy marine ecosystem for decades to come. It is long overdue that we start thinking about using nature in a different way.

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